Some Historical Developments Relating to Corrosion

*Wilson Lynes**

ABSTRACT

A chronological arrangement has been made of some developments relating to corrosion, in which references are given to papers and patents that were considered to be among the significant contributions to advancement of understanding of its nature, or control of its manifestations. Excerpts from a few of the earlier papers are given. Early developments in the electrochemical concept of corrosion are summarized.

INTRODUCTION

A systematic study of the recorded past, aside from being a fascinating pursuit, may yield practical benefits. Earlier knowledge and experience tend to be forgotten, and mistakes tend to be repeated, or work duplicated. Frequently, early observations or discoveries, the significance of which were not appreciated at the time, have had to be rediscovered, due to lack of familiarity with what previously had been done.

Furthermore, those familiar with the historical development of theories will recognize that some earlier ones, having been misinterpreted in passing through many hands, are now commonly misunderstood, or applied in a vague, imperfect way, and the observations on which they were based lost sight of. For proper understanding, it becomes necessary to consult the original sources, which is too seldom done. As Evans has so well stated: "Clearly a secondhand account of any important research, whether it be obtained from a textbook, from an abstracting journal or from a short survey . . . can be no substitute for direct consultation of the original paper."

In a rapidly developing field, such as that of corrosion, the foundations on which it is based, and the course of its development, readily become obscured. It is well to look backward occasionally for illumination and inspiration.

HISTORICAL NOTE

The science of corrosion has had two periods of rapid advancement. One, in the first half of the nineteenth century, was a result of intense and sustained scientific interest and activity aroused by the invention of the galvanic battery, and the controversy over the nature and source of the galvanic current. The other, in the first half of the twentieth century, was stimulated by growing realization of the immense economic cost of corrosion in a rapidly developing industrial age. In the latter period, a number of theories and facts established in the earlier one were rediscovered or elaborated, or both. These include the electrochemical theory of corrosion, proposed by Wollaston in 1801, developed by de La Rive in 1830, confirmed by Ericson-Aurén and Palmaer in 1901, and rediscovered by Whitney in 1903.

As early as 1819, Hall demonstrated the necessity of dissolved oxygen for appreciable corrosion of iron in water at ordinary temperatures. Yet, this fundamental consideration, overlooked by Whitney in 1903, was not firmly established until the work of Walker in 1907.

* Research Department, Revere Copper and Brass Incorporated, Rome, New York.

The importance of variations in concentration of oxygen and salts in solution in promoting localized corrosion should have been evident from experiments made prior to 1850 by Marianini, Becquerel, de La Rive, Faraday, Grove, Adie, and others. But the significance of the experiments first was only partially grasped, and then forgotten. Practical benefit from an understanding of these fundamental environmental factors did not follow until they had been observed and studied by Aston, McKay, Evans, Bengough, and others from 1916 onward. The work of these investigators, especially that of Evans and McKay, led to a shift of emphasis. Whereas, previously, heterogeneity of the metal, or dissimilar metal contact, was commonly thought to be the important or sole stimulator of corrosion, it now became widely recognized that heterogeneity of the contacting solution was often the dominant factor. Also, during this period, the importance of insoluble corrosion products as determinants of reaction rates was properly stressed.

Although the period 1850–1900 was relatively barren with respect to accomplishments in the field of corrosion, it was rich in related advances. While time was being wasted in acrimonious disputes over the acid theory of corrosion, and other false doctrines, the theories of electromotive force, ionization, and overvoltage were being developed, and the foundations laid of the thermodynamics of solutions. Thus tools became available which permitted the quantitative treatment of corrosion, which has characterized the present century.

EARLY DEVELOPMENTS IN THE ELECTROCHEMICAL CONCEPT OF CORROSION

When on May 2, 1800, W. Nicholson and A. Carlyle (1) decomposed water by a galvanic battery, a relationship between chemical action and electricity was demonstrated, and, in the same year, H. Davy (2) established the intimate connection between the electrical effects and the chemical changes occurring in the battery, and drew the conclusion of the dependence of one upon the other.

In the following year, W. H. Wollaston (3) said that it is probable that, even in the case of decomposition of water by uncoupled metals in acid solution, "the formation of hydrogen gas depends on a transition of electricity between the fluid and metal," and that "iron by itself has the power of precipitating copper by means, I presume, of electricity evolved during its solution."

In 1819 (4), L.J. Thenard, in a discussion‡ of recent papers by M. Hall and J. B. Guibourt, asserted that "iron does not decompose water at ordinary temperature when they are both perfectly pure. But once oxidation has commenced, by whatever cause, it can continue by the action of water alone." For, "iron and its oxide should be considered as two heterogeneous bodies of different electrical energy, and capable, by their contact, of effecting the decomposition of water, the same as an element of copper and of zinc in the galvanic pile." H. Davy (6), in 1826, expressed the same opinion, when he said: "In the rusting of iron, the oxide formed by the contact of moisture becomes the negative surface, and exalts the oxidation of the mass of metallic iron, and the rust consequently extends in circles."

A. de La Rive, while engaged in finding the best quality of zinc for the galvanic battery, was struck by the great difference in intensity of action of sulfuric acid on it, depending on whether this metal is pure or impure. In a paper presented in 1830 to the Society of Physics and Natural History of Geneva (7) he ascribed the fact that impure zinc is more rapidly attacked to electrical currents produced by local galvanic couples formed between zinc and its impurities, and described a number of convincing experiments in substantiation. This paper, which Palmaer has termed classic both in experimental and in theoretical respects, may be considered the beginning of the electrochemical theory of corrosion. Later, de La Rive (8) extended his theory to the atmospheric corrosion of metals, and he probably thought that all corrosion is electrochemical.

In 1827, A. C. Becquerel (9) showed that a cell may be produced by a single metal and a single fluid of two different concentrations; and R. Mallet (10) utilized this discovery in 1840 to explain localized corrosion of an iron casting reaching through a considerable depth of water at the mouth of a tidal river, it being "well known that the sea water, during the flowing of the tide, from its greater density, forces itself between the river water like a wedge, and slowly and imperfectly mixes with it, hence two strata, one of fresh or brackish water, the other of salt water below it." More than forty years later, T. Andrews thought that he was the first to discover this cause of corrosion currents, and reported measurements of potential differences developed in tidal streams in 1884 (11) and 1890 (12).

In 1847, R. Adie (13) reported interesting experiments on oxygen concentration cells. He placed two pieces of zinc, or of iron, cut side by side from the same sheet, in a running brook, the one opposed to a rapid part of the current, the other in a still place at the edge. When these were connected with a galvanometer, the piece of metal in the current acted as a "negative or platinode plate." "With both plates in the still water and a tube filled with oxygen inverted over one, the effect was the same." Adie said: "It is the greater supply of oxygen to the plate in the current which converts it into a negative or platinode. . . . A single plate of iron exposed to water and oxygen gas has local differences on its surface which act in the same way as if the iron had been in two halves and placed in a stream in the manner described. . . ."

T. Ericson-Aurén and W. Palmaer (14) developed, in 1901, an equation for the dissolving velocity of zinc in dilute acids, based on de La Rive's theory of local galvanic elements, Nernst's formula for electromotive force, and Caspari's measurements of overvoltages. Calculated values of dissolving velocity agreed very well with those obtained experimentally. This important paper, and supplementary ones (15), were largely overlooked both at the time, and later.

In 1903, W. R. Whitney (16) apparently rediscovered the electrochemical theory of corrosion. Although Whitney presented no new ideas, his paper was of considerable practical importance. He applied the theory to the corrosion of iron and steel at a time when the cost due to wastage of this major structural material was assuming disturbing proportions. For this reason, his contribution received considerable attention, and was a stimulus to further progress.

Similarly, practical benefits from application of concentration cells to metallic corrosion did not result until furthered by industrial necessity. This comparatively late development was initiated with respect to oxygen concentration cells in 1916, when applied by Aston (17) to localized corrosion of iron; and with respect to metal ion concentration cells in 1922, when applied by McKay (18) to localized corrosion of Monel.

CHRONOLOGY

The following chronological list of some developments relating to corrosion gives references to some papers and patents that were judged to be significant contributions to advancement of understanding of its nature, or control of its manifestations. Obviously, in treating so vast a subject, it is impractical to list all of the accomplishments that might be considered worthy of record. Selection, necessarily, is arbitrary and personal. Particular attention has been given to the earlier work, since it is both less known and less available.

It is the intention, insofar as is practical, to list the first reported contribution to each phase of the subject treated. In some cases, information of a reliable nature is unobtainable, and in others, undoubtedly, there are earlier references that have escaped my attention. It is a further intention to record important advances in which prior qualitative observations or conjectures have been placed on a quantitative or semiquantitative basis, or in which the significance and implications of previous observations or discoveries have been recognized and emphasized.

Many advances have been made by a series of contributions, and here assignment of credit to one or several persons, or to a particular year, is an expedient that does not properly proportion it. At best, it is an expression of opinion as to where emphasis should be placed.

The history of organized corrosion testing, being outside of the scope of this chronology, is not recorded. This does not imply lack of recognition of the importance of the work done by committees of the American Society for Testing Materials, the American Petroleum Institute, and others, here and abroad. It may be of interest to note, in passing, that the British Association for the Advancement of Science was the first scientific body to sponsor corrosion tests. In 1837 the Association made a grant of money for experiments "upon the action of sea and river water, whether clear or foul, and at various temperatures, upon cast and wrought iron," reported upon by Robert Mallet in 1838, 1840, and 1843.

Principles

1790—Passivity of Iron; J. Keir, *Phil. Trans.*, **80**, 359 (1790).

1800—Galvanic Battery; A. Volta, *Phil. Trans.*, **90**, 403 (1800).

1800—Electrochemical Theory of Galvanic Battery; H. Davy, *Nicholson's J.*, **4**, 337 (1800).

‡ This discussion is unsigned, but M. Hall (5) said it was by Thenard.

1801—Electrochemical Theory of Acid Corrosion; W. H. Wollaston, *Phil. Mag.*, **11**, 206 (1801).

1819—Electrochemical Theory of Rusting; anonymous, *Ann. chim. et phys.*, **11**, 40 (1819).

1825[1]—Differential Temperature Cell; A. Walcker, *Pogg. Ann.*, **4**, 301 (1825).

1826—Metal-Metal Oxide Cell; H. Davy, *Phil. Trans.*, **116**, 383 (1826).

1826—Differential Stress Cell; H. Davy, *Phil. Trans.*, **116**, 383 (1826).

1827[1]—Differential Solution Concentration Cell; A. C. Becquerel, *Ann. chim. et phys.*, **35**, 113 (1827).

1830—Differential Oxygen Concentration Cell; E. Marianini, *Ann. chim. et phys.*, **45**, 28 (1830).

1830—Electrochemical Theory of Corrosion of Zinc in Acid Solutions; A. de La Rive, *Ann. chim. et phys.*, **43**, 425 (1830).

1833—Faraday's Law; M. Faraday, *Phil. Trans.*, **123**, 23 (1833).

1836—Oxide Film or Oxygen Association Theory of Passivity; M. Faraday, *Phil. Mag.*, **9**, 57 (1836), and **10**, 175 (1837).

1839—Differential Illumination Cell; A. E. Becquerel, *Compt. rend.*, **9**, 561 (1839).

1842—Hydrogen and Oxygen Electrodes; W. R. Grove, *Phil. Mag.*, **21**, 417 (1842).

1852—Quantitative Experiments on Differential Oxygen Concentration Cells; Viard, *Ann. chim. et phys.*, **36**, 129 (1852).

1873-78—Theory of Thermodynamics of Solutions; "The Collected Works of J. Willard Gibbs," Vol. **1**, Longmans, Green & Company, New York (1928).

1884—Potential Measurements of Differential Solution Concentration Cells in Relation to Corrosion; T. Andrews, *Proc. Roy. Soc. London*, **37**, 28 (1884).

1887—Theory of Ionization; S. Arrhenius, *Z. physik. Chem.*, **1**, 631 (1887).

1887—Application of Thermodynamics to Conducting Solutions; J. H. vant Hoff, *Z. physik. Chem.*, **1**, 481 (1887).

1889—Theory of Electrolytic Solution Pressure; W. Nernst, *Z. physik. Chem.*, **4**, 150 (1889).

1894—Potential Measurements of Differential Stress Cells in Relation to Corrosion; T. Andrews, *Proc. Inst. Civil Engrs. London*, **118**, 356 (1894).

1899—Measurements of Hydrogen Overvoltage; W. A. Caspari, *Z. physik. Chem.*, **30**, 89 (1899).

1901-03—Quantitative Confirmation of de La Rive's Electrochemical Theory of Corrosion on Zinc; T. Ericson-Aurén and W. Palmaer, *Z. physik. Chem.*, **39**, 1 (1901); **45**, 182 (1903).

1903—Electrochemical Theory of Corrosion of Iron in Water; W. R. Whitney, *J. Am. Chem. Soc.*, **25**, 395 (1903).

1907—Experimental Study of the Function of Oxygen in the Corrosion of Iron; W. H. Walker, A. M. Cederholm, and L. N. Bent, *J. Am. Chem. Soc.*, **29**, 1251 (1907).

1910—Microbiological Corrosion; R. H. Gaines, *J. Ind. Eng. Chem.*, **2**, 128 (1910).

1914—Mechanism of Stress-Corrosion Cracking; E. Heyn, *J. Inst. Metals*, **12**, 3 (1914).

1916—Rust as a Cause of Differential Oxygen Concentration Cells; J. Aston, *Trans. Electrochem. Soc.*, **29**, 449 (1916).

1917—Mechanism of Corrosion-Fatigue; B. P. Haigh, *J. Inst. Metals*, **18**, 55 (1917).

1919—Mechanism of Cavitation; C. A. Parsons and S. S. Cook, *Engineering*, **107**, 515 (1919).

1920—Isolation of Films; R. Seligman and P. Williams, *J. Inst. Metals*, **23**, 159 (1920).

1920—Parabolic Equation of Tarnish and Oxidation; G. Tammann, *Z. anorg. u. allgem. Chem.*, **111**, 78 (1920).

1920—Mechanism of Dezincification; G. D. Bengough, R. M. Jones, and R. Pirret, *J. Inst. Metals*, **23**, 65 (1920).

1922—Logarithmic Equation of Tarnish and Oxidation; G. Tammann, *Z. anorg. u. allgem. Chem.*, **123**, 534 (1922).

1922—Quantitative Treatment of Differential Metal Ion Concentration Cells; R. J. McKay, *Trans. Electrochem. Soc.*, **41**, 201 (1922).

1923—Mechanism of Impingement Attack; G. D. Bengough, R. May, and R. Pirret, *Trans. North East Coast Inst. Engrs. & Shipbuilders*, **40**, 23 (1923).

1925—Experimental Study of the Function of Oxygen in Corrosion by Acid Solutions; W. G. Whitman and R. P. Russell, *Ind. Eng. Chem.*, **17**, 348 (1925).

1932—Quantitative Confirmation of Electrochemical Theory of Corrosion on Iron; T. P. Hoar and U. R. Evans, *Proc. Roy. Soc. London*, **137**, 343 (1932).

1933—Electron Diffraction Examination of Films; G. I. Finch and A. G. Quarrell, *Proc. Roy. Soc. London*, **141**, 398 (1933).

1933—Mechanism of Intergranular Corrosion of Austenitic Stainless Steel; E. C. Bain, R. H. Aborn, and J. J. B. Rutherford, *Trans. Am. Soc. Steel Treating*, **21**, 481 (1933).

1933—Electrochemical Theory of Tarnish and Oxidation; C. Wagner, *Z. physik. Chem.*, **21B**, 25 (1933).

1934—Theory of Microbiological Anaerobic Corrosion; A. H. von Wolzogen Kühr and L. S. van der Vlugt, *Water*, **18**, 147 (1934).

1936—Langelier Index; W. F. Langelier, *J. Am. Water Works Assoc.*, **28**, 1500 (1936).

1939—Electron Configuration Theory of Passivity; H. H. Uhlig and J. Wulff, *Trans. Am. Inst. Mining Met. Engrs.*, **135**, 494 (1939).

[1] More conclusive evidence on the influence of temperature and concentration differentials was obtained by M. Faraday in a series of beautiful experiments described in *Phil. Trans.*, **13**, 93 (1840).

Corrosion-Resistant Alloys

Ca. 1860—Aluminum Bronze; B. S. Proctor, *Chem. News*, **4**, 58 (1861).

Ca. 1890—Admiralty Brass; "Handbook on Nickel-Copper Alloy Condenser Tubes," The Mond Nickel Company, Ltd., London.

1906—Monel Metal; A. Monell, U. S. Pat. 811,239 (1906).

1911[2]—Copper Bearing Steel; (American Sheet and Tin Plate Company) D. M. Buck, *Yearbook Am. Iron Steel Inst.*, **10**, 373 (1920).

1912—Austentic Chromium-Nickel Stainless Steel; E. Maurer and B. Strauss, German Pat. 304,126 and 304,159 (1912).

1913—High Silicon Cast Iron (Duriron); "Process Industries Handbook of Corrosion Resistant Materials," p. 195, McGraw-Hill Publishing Company, Inc., New York (1931).

1916[3]—Chromium Stainless Steel; H. Brearley, U. S. Pat. 1,197,256 (1916).

1922—Arsenical Admiralty; Discussion by G. D. Bengough and R. May of Paper by R. B. Abrams, *Trans. Electrochem. Soc.*, **42**, 39 (1922).

1925—Silicon Bronze; C. B. Jacobs, U. S. Pat. 1,539,260 (1925).

1926—Chromium-Nickel-Molybdenum Stainless Steel; B. Strauss, U. S. Pat. 1,587,614 (1926).

1926—70-30 Cupro-Nickel; "Handbook on Nickel-Copper

[2] In 1900, F. H. Williams (19) reported experiments indicating that 0.40 per cent copper increased the corrosion resistance of wrought iron and mild steel subjected alternately to the action of air and water, but an alloy of this type was not commercially available until eleven years later.

[3] Brearley's patent marked the beginning of industrial usefulness, but P. Monartz previously had established a comprehensive background of knowledge. The results of his brilliant investigations on chromium steels appeared in *Rev. mét.*, **8**, 161, 193 (1911).

Alloy Condenser Tubes," The Mond Nickel Company, Ltd., London.

1929—Aluminum Brass; R. S. Hutton, British Pat. 308,647 (1929).

1929—Inconel; P. D. Merica, British Pat. 328,362 (1929).

1929—Hastelloy A; B. E. Field, *Trans. Am. Inst. Mining Met. Engrs.*, 149 (1929).

1933—Titanium Inhibited Austenitic Chromium-Nickel Stainless Steel; E. Houdremont and P. Schafmeister, *Arch. Eisenhüttenw.*, **7**, 187 (1933).

1939—Hastelloy C; F. T. McCurdy, *Proc. Am. Soc. Testing Materials*, **36**, 698 (1939).

1939—Iron Bearing 70-30 Cupro-Nickel; *Bull. British Non-Ferrous Metals Research Assoc.*, **D31** (Jan. 1939).

Protective Coatings

Ca. 1500—Tin Plate; *Bull. Intern. Tin Research Development Council*, No. 4 (Oct. 1946).

1836—Cement-Lined Cast Iron Pipe; J. Herschel, *Compt. rend.*, **3**, 506 (1836).

1837[4]—Galvanized Iron; H. W. Craufurd, British Pat. 7355 (1837).

1840—Hot Coal Tar; R. Mallet, *Brit. Assoc. Advancement Sci. Rept.*, **9**, 221 (1840).

1840—Silver Electro-Plating; G. E. and H. Elkington, British Pat. 8447 (1840).

[4] Craufurd's patent of 1837 and S. Sorel's French patent 11,773 of 1840 were the basis of the development of the galvanizing industry. The first recorded experiments on hot-dipped zinc coatings are those of Malouin, *Mém. acad. roy.*, p. 100 (1742).

1869[5]—Nickel Electro-Plating; Isaac Adams, U. S. Pat. 93,157 (1869).

1906—Phosphate Coatings; T. W. Coslett, British Pat. 8667 (1906).

1908—Zinc Chromate Pigment; A. S. Cushman, *Science*, **27**, 666 (1908).

1909—Synthetic Resin (Bakelite); L. E. Baekeland, U. S. Pat. 942,809 (1909).

1923—Anodized Aluminum; G. D. Bengough and J. M. Stuart, British Pat. 223,994 (1923).

1927—Alclad Sheet; E. H. Dix, Jr., *Natl. Advisory Comm. Aeronaut. Tech. Note*, No. 259 (Aug. 1927).

Protective Treatments

1824—Cathodic Protection; H. Davy, *Phil. Trans.*, **114**, 151 (1824).

1828—Alkaline Inhibitors ($Ca(OH)_2$ and $Mg(OH)_2$); M. Hall, *Quart. J. Sci.*, **25**, 262 (1828).

1872—Organic Inhibitors (essential and fixed oils); C. Marangoni and P. Stefanelli, *J. Chem. Soc.*, **25**, 116, (1872).

1907—Chromate Inhibitor; A. S. Cushman, Bull. 30, Office Public Roads, U. S. Dept. Agriculture.

Ca. 1908—Hot Water Vacuum Deaeration; W. H. Walker, *Trans. Electrochem. Soc.*, **14**, 175 (1908).

1910—Cathodic Protection by Applied Current; E. Cumberland, *J. Inst. Metals*, **15**, 192 (1916).

1912—Cathodic Protection of Underground Structures; Consolidated Edison Company of New York, Incorporated, Private Communication from L. J. Gorman.

1917—Cold Water Vacuum Deaeration; P. V. O'Brien and J. Parr, *Proc. Inst. Civil Engrs. London*, **205**, 310 (1917–18).

[5] First patented by James Shore in 1840, British Pat. No. 8407, but Isaac Adams' patent of 1869 marked the establishment of commercial production.

APPENDIX

SOME EARLY OBSERVATIONS ON THE NATURE OF CORROSION

Electrochemical Theory of Corrosion

1. W. H. Wollaston, *Phil. Mag.*, **11**, 206 (1801).

"We know that when water is placed in a circuit of conductors of electricity, between the two extremities of a pile, if the power is sufficient to oxidate one of the wires of communication, the wire connected with the opposite extremity affords hydrogen gas.

"Since the extrication of hydrogen, in this instance, is seen to depend on electricity, it is probable that, in other instances, electricity may be also requisite for its conversion into gas. It would appear, therefore, that in the solution of a metal, electricity is evolved during the action of the acid upon it; and that the formation of hydrogen gas, even in that case, depends on a transition of electricity between the fluid and the metal.

"We see, moreover, in the first experiment, that the zinc, without contact of any other metal, has the power of decomposing water; and we can have no reason to suppose that the contact of the silver produces any new power, but that it serves merely as a conductor of electricity, and thereby occasions the formation of hydrogen gas.

"In the third experiment also, the iron by itself has the power of precipitating copper by means, I presume, of electricity evolved during its solution; and here likewise the silver, by conducting that electricity, acquires the power of precipitating the copper in its metallic state."

2. A. de La Rive, *Ann. chim. et phys.*, **43**, 425 (1830).

"Being recently engaged in finding the best quality of zinc for the construction of galvanic piles, I was singularly struck by a fact that most chemists, no doubt, have noted: namely, the great difference in intensity of action of sulfuric acid on zinc, depending on whether this metal is pure or impure. Zinc purified by distillation, when placed in sulfuric acid solution, is scarcely attacked, especially at first, and even after a long time evolves only a few small, slowly rising bubbles of hydrogen gas; while commercial zinc, under the same circumstances, produces an enormous quantity of hydrogen which is liberated with the effervescence and vivacity well known to those who have prepared this gas. I have been curious to know what could be the cause of this difference, which does not appear to me to have attracted the attention of investigators as much as it should, and I have obtained in this respect some results that I take the liberty of communicating to the Society [of Physics and Natural History of Geneva].

. . . . . .

". . . the circumstances which accompany the phenomenon in question are of a nature to make us presume that it is probably due, in whole or in part, to some electrical or rather electrochemical action.

"The first of these circumstances is the influence exercised by the presence of a foreign metal mixed with the pure zinc, in activating the decomposition of water and the disengagement of hydrogen.

"The second is that the acid solutions which produce by their action on impure zinc the greatest quantity of hydrogen are precisely those which have the highest electrical conductivity . . . .

"A final fact, which tends to confirm the hypothesis that we have advanced above on the nature of the phenomenon that we are investigating, is what occurs when metallic contact is established between a cylinder of distilled zinc in acid solution, and a platinum wire in the same liquid. A large number of bubbles of hydrogen gas are evolved around the platinum wire, and the total quantity of gas produced when there is contact between the zinc and platinum is more than double that which is produced when the zinc is isolated . . . .

. . . . . .

"It follows from the preceding that we may consider that what occurs in the case of the zinc mixed with foreign substances is analogous to the case of the zinc attached to a platinum wire; the slight chemical action which occurs on the pure zinc is produced by an electrical current, which is established between each molecule of zinc and the foreign molecule in contact with it. These little molecular currents decompose the water that they traverse, carrying hydrogen to the foreign molecule which is negative in all of the alloys that I have made, and transporting oxygen to the molecule of zinc which is positive. . . . The intensity of these currents should depend on the conductivity of the acid solution . . . [and] also on the difference of oxidizability of zinc and of the substance mixed with it. . . .

. . . . . .

". . . chemical analysis . . . [demonstrates] the presence in commercial zinc . . . of traces of tin, of lead, and of a little more than one per cent of iron. Now, we have seen above that an alloy of one part of iron and nine parts of pure zinc . . . makes the distilled zinc capable of producing as much gas as commercial zinc. But I am assured by several experiments that it is not necessary that the iron be in as large a quantity in the alloy, and that less than two per cent of iron filings mixed with the pure zinc can make it capable of developing in the different acid solutions, exactly as much hydrogen as commercial zinc. Let us note again that we can explain in the same manner why distilled zinc is more attacked when the action has been in progress for several hours than when it commences; it is because then its surface is already a little oxidized, and the presence of this oxide plays a role analogous to that of a foreign negative metal. . . .

. . . . . .

"Before closing I shall cite further data which appear to confirm the existence of molecular currents which, according to our hypothesis, are established on the surface of zinc attacked by acid solution. These facts testify to the electrical power of different types of zinc. In connecting them successively in pairs through a galvanometer, and placing them in very dilute sulfuric acid solution (solution No. 3) I found that I could arrange them in the following order, each one being positive with respect to the preceding one, when commencing at the positive end; distilled zinc, zinc-lead, zinc-tin, zinc-iron, commercial zinc, and zinc-copper."

3. T. Ericson-Aurén and W. Palmaer, *Z. physik. Chem.*, **39**, 1 (1901).

"Conclusions

"1. We have attempted to explain the dissolving of metals by choosing as an example the especially simple case of the dissolving velocity of zinc in dilute acids.

"2. It has been shown that the results of our experiments cannot be explained by applying the Law of Mass Action in the usual manner.

"3. It has been shown that the results of the experiments can be explained if one assumes that the dissolving of metals is caused by local galvanic currents.

"4. The slow dissolving of pure metals is one conclusion of the theory of local galvanic currents.

. . . . . .

"7. The general formula for the dissolving velocity, q, of a metal is:

$$q = f\frac{x}{C}e$$

$$\text{or } q = f\frac{x}{C}\left(\frac{0.0576}{n}\log\frac{P_1}{p_1} - 0.0576\log\frac{P_2}{p_2} - \pi\right)$$

where, f = a proportionality factor
x = conductivity of the solution
C = resistance capacity of the local galvanic elements
e = the electromotive force of the local galvanic elements
n = valency of the metal
P_1 = electrolytic solution pressure of the metal
p_1 = osmotic pressure of the ions of the metal in solution
P_2, p_2 = the same quantities for hydrogen
π = overvoltage of the impure metal

"8. The above formula shows that the dissolving velocity is determined by the electromotive force of the local cells, the conductivity of the solution, and the resistance capacity of the local cells; the proportionality factor, f, is determined by the dimensions adopted for the dissolving velocity. The electromotive force of the local cells and conductivity of the solution can in many cases be calculated; thus the only remaining unknown is the resistance capacity. However, the electromotive force and the conductivity can always be determined experimentally. Where q, x, and e are known the resistance capacity can be calculated, after which in other cases the dissolving velocity can be calculated."

. . . . . .

4. W. R. Whitney, *J. Am. Chem. Soc.*, **25**, 395 (1903).

"Practically the only factor which limits the life of the iron is oxidation, under which are included all the chemical processes whereby the iron is corroded, eaten away, or rusted. In undergoing this change, the iron always passes through or into a state of solution, and, as we have no evidence of iron going into aqueous solution except in the form of ions (probably electrically charged atoms) we have really to consider the effects of conditions upon the potential-difference between iron and its surroundings. The whole subject of corrosion of iron is therefore an electrochemical one, and the rate of corrosion is simply a function of electromotive force and resistance of circuit. If now we apply Nernst's conception of the source of electromotive force between a metal and a solution, we must conclude from the measured potential-difference that iron in contact with an aqueous solution tends to dissolve, ionize, or oxidize with a force expressed as equivalent to about 10,000 atmospheres' pressure at ordinary temperature.

. . . . . .

"Hydrogen acts as a metal and is electrolytically classified in the group with copper when compared with iron and zinc. That is, if a cell were made upon the Daniell model, iron being used instead of zinc, and hydrogen in place of copper, the cell would generate a current when the iron and hydrogen electrodes were connected. Iron would then dissolve with a velocity dependent on the total resistance of the circuit. So also, and for the same reason, iron when placed in a solution containing hydrogen ions will dissolve as the hydrogen precipitates, just exactly as when placed in the copper salt solution. That iron does oxidize or dissolve in all solutions containing appreciable quantities of hydrogen ions is well known. This electrochemical relationship between iron and hydrogen is the primal cause of rusting."

Oxygen Depolarization

5. A. de. La Rive, "Traité d'Électricité Théorique et Appliquée," Vol. **2**, p. 803, J. B. Baillière, Paris (1856).

". . . the oxidation of a metal in air is not the simple result of the direct combination of this metal with oxygen; a more complex phenomenon occurs, that is a galvanic action, the metal decomposing the water by a local galvanic action, aided by the presence of dissolved oxygen which acts on the hydrogen of this water; the presence of carbonic acid facilitates the action by making the water more conductive."

6. T. Ericson-Aurén and W. Palmaer, *Z. physik. Chem.*, **45**, 182 (1903).

"If a depolarizer, which is able to oxidize the hydrogen, is present in the solution, the electromotive force of the local element, and thus the dissolving velocity, must increase. This has been directly demonstrated by Weeren [*Ber.*, **24**, 1785 (1891)], although he explained the phenomenon in another way. According to the theory of local cells it is, thus, easily explained why, for instance, copper, mercury, and silver, which are not able to evolve hydrogen, are easily dissolved in nitric

acid. As is well known, nitric acid is an efficaceous depolarizer for hydrogen, and the dissolving proceeds with simultaneous reduction of the nitric acid."

7. W. H. Walker, A. M. Cederholm, and L. N. Bent, *J. Chem. Soc.*, **29**, 1251 (1907).

"The rapidity with which iron will pass into solution in water depends not only upon the electrolytic solution pressure of the iron and hydrogen, and the osmotic pressure of the iron ions already in solution, but also upon the "excess voltage" (überspannung) which is required in order that the hydrogen ion which passes from the ionized condition may be set free. In this case there is a counter electromotive force which must be overcome before the hydrogen can be liberated. It is possible, therefore, that the quantity of iron which can dissolve in water is limited to that amount which is equivalent to the hydrogen necessary to polarize that portion of the specimen which acts as the cathode. If this is the case, we should be able to make this solvent action continuous by the addition of any reagent which will depolarize the hydrogen-covered cathode portion. . . .

. . . . . .

"We have . . . shown that the primary function of oxygen in the corrosion of metals is in depolarizing those cathodic portions of the iron upon which hydrogen tends to precipitate, and that a secondary function is the oxidation of the ferrous ion to the ferric form, with its subsequent precipitation as ferric hydroxide . . . [and] that the rapidity of corrosion in water is a linear function of the partial pressure of the oxygen in the atmosphere above the water."

Differential Oxygen Concentration Cell

8. R. Adie, *Phil. Mag.*, **31**, 351 (1847).

"Perhaps the experiments of the most importance for determining the theory of the action of gas absorbing galvanic couples are those where one metal only is excited by oxygenated water; to illustrate this action I made the following experiments:

"Two slips of zinc cut side by side from the same sheet were placed in a running brook, the one opposed to a rapid part of the current, the other in a still place at the edge. Connecting these in the usual manner with the galvanometer, there was a permanent deflection of 25°; and on changing the respective places of the plates in the stream without disturbing their attachments to the galvanometer, the needles immediately passed to the opposite side of the card; in both cases the piece of zinc in the current acted as a negative or platinode plate. With both plates in still water and a tube filled with oxygen inverted over one, the effect was the same. It is the greater supply of oxygen to the plate in the current which converts it into a negative or platinode. A cell containing two small silver wires and the cyanide of silver solution used for electroplating was attached in place of the galvanometer, when, after a lapse of two hours, metallic silver was seen precipitated in a minute quantity on the silver wire connected with the piece of zinc in still water.

"Two plates of iron were placed in the stream, under like conditions to the zinc; after two hours metallic silver was distinctly seen precipitated on the silver wire connected with the iron plate in still water.

"The fact here shown, of two similar pieces of iron giving rise to a galvanic current capable of precipitating metallic silver, appears to me to be important, for it proves that the electricity, in passing through the water intervening between these two plates, either decomposes it with the aid of oxygen in solution, or that oxygenated water forms a binary compound, capable of acting as an electrolyte.

"The fact of iron and oxygen uniting together at ordinary temperatures when moisture is present is well known. It is the office performed by the water during this union, wherein lies the true ground of the theory of gas-absorbing batteries. A single plate of iron exposed to water and oxygen gas has local differences on its surface which act in the same way as if the iron had been in two halves and placed in a stream in the manner described: the oxidation of the iron is developing a voltaic current which passes through the fluid from one point of the plate to another, either by a process of decomposition and recomposition of water, or by the decomposition of the compound formed by the solution of the gas in water.

. . . . . .

"In concluding these experiments, I may again notice that a tube of oxygen suspended over a plate of iron in still water has the same effect as the current of the stream, converting the oxygenated plate into a platinode. The carbonic acid present in all surface water may by some be thought to perform an essential part in the ordinary rusting of iron. But where every care is taken to exclude this gas from a tube filled with oxygen, a small quantity of water and a piece of iron, the oxidation of the iron proceeds with rapidity, accompanied by changes which appear to me to preclude the idea that even a trace of carbonic acid can be essential. The oxygen gas disappears; at first an abundant formation of red or peroxide of iron is seen; then, after the supply of oxygen has decreased, the green-colored protoxide is gradually formed. These two oxides afterwards begin slowly to unite, and form the well-known black or magnetic oxide. In an experiment of this kind every trace of the red and green-colored oxides had disappeared at the end of three months from the time of closing the tube, and there remained only an inky precipitate, which was proved to be the black oxide of iron."

9. J. Aston, *Trans. Electrochem. Soc.*, **29**, 449 (1916).

"There is every evidence that the effect of rust, wet rust at any rate, is not as an electrode, but as a mechanical covering, which influences the polarity of the underlying iron. . . .

. . . . . .

"The underlying feature appears to be the relative access of oxygen to the surfaces of the electrodes. The electrolyte (moisture) must reach both; then that to which oxygen has the more free access becomes the cathode, and the other is the anode. If two bare iron electrodes are separated by a partition of porous earthenware, parchment, etc., either may be made the cathode by bubbling air into this compartment, and not into the other, or by merely lifting one into the air and then reimmersing it. . . .

"Wet rust or similar coating upon one electrode plays the role of a diaphragm permeable to the moisture, but preventing or slowing down the oxygen penetration. Anodic solution of the underlying iron results, with oxidation and precipitation as greenish ferrous hydroxide. This colloid, migrating outwards under the directive influence of the current flow, is in turn oxidized to ferric hydroxide nearer to the exposed surface of the rusted anode. The effect of rust and oxygen is well illustrated by local rusting of an iron sheet which has air bubbling up one strip or zone. Contrary to general expectation, this air supplied zone remains clear, while the adjoining areas are anodic and become coated."

Differential Solution Concentration Cell

10. R. Mallet, *Brit. Assoc. Advancement Sci. Rept.*, **9**, 221 (1840).

"I would here remark a cause of increased corrosive action, affecting castings, such as cast iron pilings, etc., at the mouths of tidal rivers, which has not, to my knowledge, struck previous observers.

"It is well known that the sea water, during the flowing of the tide, from its greater density, forces itself beneath the river water like a wedge, and slowly and imperfectly mixes with it, hence two strata, one of fresh or brackish water, the other of salt water below it. . . . Now Becquerel has proved that a homogeneous metallic surface (a rod or wire for instance), exposed to the action of a fluid menstruum, will assume a state of electrical tension, provided that the fluid in which it is immersed be of different density in two strata, i.e.

of different corrosive power. In fact, the metal and the two layers of fluid constitute a voltaic pile of one solid and two fluid elements; hence as one end of the metallic rod will be in a positive state with respect to the other, it will be corroded faster than the other. Now this is precisely the condition of any casting reaching through a considerable depth of water at the mouth of a tidal river. The water is saltier below than above, the part of the casting immersed therein (the lower end of a cast iron pile for instance) will therefore be in an opposite electrical condition to that of the portion above, and the amount of corrosion of the positive element due to the kind of iron and the state of the water will be further increased or "exalted" by the negative condition of the opposite end which will be itself in the same proportion preserved."

11. R. J. McKay, *Trans. Electrochem. Soc.*, **41**, 201 (1922).

In a recent study of the rate of corrosion of acid-resisting metals in acid solutions, a type of electrolytic corrosion which is ordinarily neglected in considering corrosion in general was shown to be of importance. This action is that of electrolytic cells which corrode metal in certain anodic areas, the position of these areas and the electromotive force of the cell being governed by differences in the concentrations of the substances dissolved in the corroding solution. . . .

"In the corrosion of acid-resisting metals by the acid solutions used in pickling steel sheets, a small amount of copper from the metals may go into solution. Under certain conditions it is found that variations in the amount of copper in solution would produce an E.M.F. as high as 0.2 volt. This voltage in the highly conducting acid solutions will produce rates of corrosion up to 50 times the normal rate, thus, under the worst conditions, reducing the service of a piece of apparatus from a period of years to as many weeks. This extreme condition is not usually reached in practice, but it is approached nearly enough that the corrosion of these cells is an extremely serious matter to the steel pickler.

"In addition to this particular type of cell it has been demonstrated that economically important corrosion may be produced by cells due to differences in the concentration of acids, concentrations of dissolved oxygen or hydrogen, or concentration of dissolved oxidizing and reducing salts, for example the presence of ferric iron at one point and of ferrous iron at another. These cells may, therefore, be quite widely distributed."

Passivity of Iron

13. M. Faraday, *Phil. Mag.*, **10**, 175 (1837).

"I am much obliged to you for a sight of M. Schoenbein's paper, the experiments and observations in which are excellent. The cause of the phenomena he has so well distinguished is indeed exceedingly difficult to be distinguished at present, and I was in hopes that the doubt on my mind when I ventured the view referred to would be evident from my words, 'My strong impression is,' etc. Moreover, M. Schoenbein, and also M. Alb. Mousson, in an attempt which he has made to explain the cause, have not given my view clearly. I have said, that my impression is, that the surface of the metal is oxidized, or else that the superficial particles of the metal are in such relation to the oxygen of the electrolyte as to be equivalent to an oxidation; meaning by that, not an actual oxidation, but a relation like that of the particles of amalgamated zinc to the oxygen of the water in dilute sulphuric acid before the electric current which tends to be formed is established. (See Experimental Researches, Eighth Series, par. 949.)

"The state seems to me to be one of a very delicate equilibrium of forces, though of course that condition of things which can produce it can also retain it; and this notion seems to be confirmed by the intermitting action originally mentioned by Herschel. . . .

"I was somewhat struck the other day, whilst reading in your useful 'Scientific Memoirs' M. Nobili's paper on a new chromatic scale, on finding that he accounts for the colors of his thin plates by assuming films of oxygen and acid; which he considers as adhering permanently to the surfaces of the platina, iron and steel plates which he used in his experiments, without however being in combination, chemically, with the metal. This is going much further in the idea of association without combination than I have done. . . ."

Corrosion of Iron

13. M. Hall, *Quart. J. Sci.*, **7**, 55 (1819).

"It has been generally supposed by chemists, that water, in imparting oxygen to iron, undergoes a decomposition, its hydrogen being evolved whilst its oxygen enters into combination with the metal. This decomposition of the water and evolution of hydrogen gas have been represented as taking place slowly, at the ordinary temperatures of the atmosphere.

"It is the object of this memoir, to detail a series of experiments which appear to prove the incorrectness of this opinion; and to establish the fact, that, in ordinary oxidation of iron by moisture or water, the action of the water is necessarily combined with that of atmospheric air or oxygen gas. The error appears to have originated in an inattention to this co-operative influence of the atmospheric air absorbed by the water, in inducing the oxidation of the iron,—to the changes induced in the atmospheric air itself,—and to inaction of iron in perfectly pure water.

. . . . . .

"Water may be freed from its admixture of atmospheric air by long boiling; but it may be deprived of any oxygen it may have absorbed, perhaps still more satisfactorily, as will be stated more expressly hereafter, by being subjected for some time to the action of iron filings, or of a number of bright iron plates. In either case, if portions of bright or polished iron be exposed, at an ordinary temperature, to the action of the water thus purified, the metal retains its lustre unimpaired. The water, therefore, does not appear to undergo the decomposition, or the iron the oxidation, hitherto supposed to take place in these circumstances.

. . . . . .

"If a jar, containing portions of iron plate at its lower part, be occupied by water, so as to rise an inch or more above the iron, and by superincumbent atmospheric air, so as to fill the remaining space, the volume of this air diminishes gradually, until at length about four-fifths of the original quantity alone remains. This residual gas extinguishes the flame of a candle, is incapable of combustion, and possesses all the properties of nitrogen gas. The surface of the iron becomes completely oxidated. If this experiment be made with pure oxygen, this gas is at length completely absorbed."

14. R. Adie, *J. Chem. Soc.*, **1**, 12 (1849).

"In the trials described in the former paper, when zinc and iron acted as the positive elements of couples excited by boiling water, the galvanometer showed that the difference between them was only one of degree. With zinc, after long boiling, the galvanometer was deflected 20°, and with iron 7°, from which I was led to think, that although iron was usually held incapable of rusting in pure water, it might, like zinc, possess the power of slowly decomposing water, but that the quantity of oxide formed in this manner was so small, that it had hitherto escaped notice. . . .

"The experiment, in which zinc and copper elements decomposed water in a hermetically sealed tube, occupied so long a time that I despaired of obtaining any notable effect with iron, unless a large surface was brought into action. For this purpose some iron was reduced from the red oxide by a stream of hydrogen. . . . Iron, subdivided in this manner, was placed with distilled water in two tubes of hard glass; these tubes were then heated to the boiling temperature, and hermetically sealed. A third tube was similarly prepared, in which a surface of 45 inches of bright polished iron wire was substituted for the pyrophoric iron.

. . . . . .

". . . at the expiration of a month, one of them, containing pyrophoric iron, was opened, and the gas, having been transferred to a detonating tube, was exploded with oxygen. At the end of two months the gas from the cell containing the iron wire was likewise detonated with oxygen.

. . . . . .

"These experiments clearly establish the fact that iron is capable of slowly decomposing water at ordinary temperatures. I believe that if iron and water could be brought together, perfectly free from oxide of the metal or from oxygen gas dissolved in the water, that no decomposition could ensue; but this is a condition that cannot be attained in practice."

REFERENCES

1. W. Nicholson and A. Carlyle, *Nicholson's J.*, **4**, 179 (1800).
2. H. Davy, *Nicholson's J.*, **4**, 337 (1800).
3. W. H. Wollaston, *Phil. Mag.*, **11**, 206 (1801).
4. Anonymous, *Ann. chim. et phys.*, **11**, 40 (1819).
5. M. Hall, *Quart. J. Sci.*, **25**, 262 (1825).
6. H. Davy, *Phil. Trans.*, **116**, 383 (1826).
7. A. de La Rive, *Ann. chim. et phys.*, **43**, 425 (1830).
8. A. de La Rive, "Traité d'Électricité Théorique et Appliquée," Vol. **2**, p. 803, J. B. Baillière, Paris (1856).
9. A. C. Becquerel, *Ann. chim. et phys.*, **35**, 113 (1827).
10. R. Mallet, *Brit. Assoc. Advancement Sci. Rept.*, **9**, 221 (1840).
11. T. Andrews, *Proc. Roy. Soc. London*, **37**, 28 (1884).
12. T. Andrews, *Trans. Fed. Inst. Mining Engrs.*, **1**, 191 (1890).
13. R. Adie, *Phil. Mag.*, **31**, 351 (1847).
14. T. Ericson-Aurén and W. Palmaer, *Z. physik. Chem.*, **39**, 1 (1901).
15. *Ibid.*, **45**, 182 (1903); **56**, 689 (1906).
16. W. R. Whitney, *J. Chem. Soc.*, **25**, 395 (1903).
17. J. Aston, *Trans. Electrochem. Soc.*, **29**, 449 (1916).
18. R. J. McKay, *Trans. Electrochem. Soc.*, **41**, 201 (1922).
19. F. H. Williams, *Proc. Engrs. Soc. West. Penn.*, **16**, 231 (1900)

Feature Section

Volta and the Volt

George W. Vinal

The year 1950 marks the sesquicentennial of Volta's announcement of his famous pile and crown of cups. In a letter to Sir Joseph Banks, who was then the President of the Royal Society of London, Volta wrote in great detail of his discoveries and of the many experiments which he had made with his new and novel apparatus. His letter, dated March 20, 1800, was published in French in the *Philosophical Transactions of the Royal Society* [**90,** 403 (1800)]. It came at a time when the world was ready and waiting for a better source of electrical energy than it then had. Batteries as we know them today became possible and for the first time experimenters were provided with a means of generating electricity in considerable and manageable quantities. It is fitting, therefore, that on this sesquicentennial anniversary we should take note of Volta's contribution to science and to some of the subsequent developments to which it led.

Before Volta's time, electrical experiments had been sensational, but of little practical value. Knowledge of electrical phenomena had accumulated slowly during the preceding centuries. In the course of time, frictional machines had been made to generate static charges; the distinction between conductors and nonconductors had become known; the Leyden jar had been invented; and the principle of series and parallel connections of capacitors, which in groups were called batteries, had been established. Nevertheless, Benjamin Franklin wrote in 1749 that he was chagrined that nothing had been produced of use to mankind.

The tempo increased during the latter part of the eighteenth century. Galvani's famous experiment with the frog's legs led him to a theory of animal electricity. This undoubtedly influenced Volta's early work, although Volta eventually arrived at a different and more correct conclusion.

Volta's letter led to experiments of far-reaching importance in England and elsewhere. The effect of the letter was immediate. Within six weeks of the time it was dispatched from Italy, Nicholson and Carlisle in England had constructed a pile and with it effected the electrolytic decomposition of water. Experiments which we may call electrochemical became the order of the day. Metals were produced electrolytically. Sir Humphry Davy decomposed the fixed alkalies, as they were then called, and saw the first metallic potassium. He demonstrated the "full splendors of the electric arch" (arc) between carbon rods. These experiments, to mention only a few, were made possible by the use of electric batteries, following Volta's discovery.

Pile and Crown of Cups

Volta's pile and crown of cups had their limitations. The pile dried out in a few days and the crown of cups was too voluminous to be convenient. Early experimenters were quick to make improvements. Duplex electrodes appeared in 1800; plunge batteries came a few years later; batteries grew in size and power, yet during the first third of the nineteenth century the principles remained essentially the same as those described by Volta. For many years after Volta's time, batteries continued to be the principal source of electrical energy, but less was said of them than of the results that they produced. Faraday's great discovery of electromagnetic induction in 1831 laid the foundation for a new and still greater source of electrical energy, still it was not until the latter part of the century that generators and central station power became a reality.

Volta's letter opens with the statement that he had obtained remarkable results in pursuing his experiments on electricity excited by the simple contact of different kinds of metal and other conductors. He compared his apparatus with Leyden jars, but unlike these his new apparatus could give repeated shocks. He said that it restored itself, and unlike the Leyden jar it did not require charging initially by an ex-

Dr. George Wood Vinal, retired chief of the Division of Electrochemistry at the National Bureau of Standards, is the most recent recipient of The Electrochemical Society's Edward Goodrich Acheson Medal and Prize. The award was presented to him at a banquet in his honor, held October 12, 1950, at the 98th Meeting of the Society, Buffalo, New York (Dec., 1950, JOURNAL). Taking part in the ceremonies were President Charles L. Faust, Battelle Memorial Institute, who gave a brief history of the award; Dr. Marion Eppley, president of The Eppley Laboratories, who gave an interesting account of the personal traits of the medalist; and Dr. Wallace A. Brode, Assistant Director of the NBS, who reviewed Dr. Vinal's outstanding technical accomplishments.

Dr. Vinal, a member of The Electrochemical Society since 1923, is a recognized international authority on standard cells, and in the fields of primary and secondary batteries. He is also noted for his work in establishing the values for the international volt and ampere (Sept., 1950, JOURNAL). In view of this, it was fitting that he chose as the topic of his medalist's address, "Volta and the Volt."

ternal source. He described the materials which he used in the pile and their assembly. Discs of copper, or better silver, against tin, or better zinc, as he said in his quaint way, and an equal number of discs of pasteboard or hide well soaked in water or a "humeur," which is a better conductor, were arranged in a certain manner. He laid great stress on this certain manner. Obviously there were many ways in which these pieces could have been piled up to produce no worth-while result, but the certain manner is clearly the first of his great contributions. In the manner he described, he assembled piles of 20, 40, 60, or as many pairs of metals in vertical columns as could sustain themselves without falling down. Another great contribution was the series connection of individual cells, as we would say today.

Electrical Effects

How could Volta measure the electrical effects of his pile and crown of cups? He mentioned an electrometer, but his chief reliance seems to have been on the sensation of pain, even to producing numbness of his arms by contact with parts of his apparatus. To feel the shocks under the best conditions he moistened his fingers and then found that he could detect the "electric fluid" from 3 or 4 couples. With each added couple the shocks became stronger. Forty or fifty couples gave shocks more than mediocre to the arms of one person and appreciable shocks to several persons holding hands in a chain. All this may seem very simple now and as one would expect; one hundred and fifty years ago these experiments were new and the results surprising. They mark the man as truly a pioneer.

The crown of cups which he described was a modification of the pile. It was fundamentally the same in principle, but better adapted to some of his later experiments. Goblets or other glass vessels were placed on a table in a more or less circular arrangement. The metals, either copper or silver against tin or zinc, were connected in pairs which linked the adjacent vessels throughout the entire line. The solution which filled the vessels was dilute lye when he used tin, or a solution of common salt when zinc was employed. With this arrangement he could immerse his fingers or his whole hand in any of the vessels and thus test the strength of the "electric fluid," as he called it. The first and last vessels in a line of cells which numbered 20, 40, or 60, as pleased him, were brought near together and from this circular arrangement came the name, circle or crown of cups.

Volta said that one can understand easily that to experience the shocks, it sufficed to plunge the hand in one of the goblets and a finger of the other hand in another goblet sufficiently removed from the first. The shocks became stronger the farther apart these goblets were in the circle.

Volta then made a very interesting experiment with three connected groups of 20 cells each. In the first group of 20 cells all the silver plates were at the left and all the zinc plates at the right. The second group was in the reverse order. The third group was placed similarly to the first group. One group was therefore connected counter to the other two groups. With a finger in the first goblet of the first group, touching successive connections with the other hand, he began to feel a slight shock at the 4th or 5th "arc" (connection). The shocks increased up to the 20th cell, while in passing on to the other cells connected in the contrary sense, the shocks became perceptibly less until at the 36th or 37th goblet they were imperceptible and became absolutely null at the 40th goblet. Continuing with the third group of cells, the shocks again became perceptible at the 44th or 45th goblet and increased in severity until at the 60th cell the shock was equal to that of a group of 20 cells. Volta then said: "But if the middle group of goblets is turned in the same sense as the first and third groups, the effect is very great and the shock strong." He observed that a break in any part of the circuit resulted in no effect.

Electromotive Forces

In the language of today, Volta observed the balancing of electromotive forces when one group of cells was connected in opposition to a similar group. This principle is today used in the precise comparison of electromotive forces. A standard cell which may be sent to the National Bureau of Standards for certification of its electromotive force is connected in opposition to another cell whose electromotive force is known. Even with a relatively simple circuit and a good galvanometer, the electromotive force of the cell under test can be determined to within one part in one million.

Think of a man of Volta's time who without the benefit of instruments or of modern theory could make so accurate a statement on the basis of the pain which he experienced on touching various parts of his circle of cups. Volta clearly understood the significance of what we would now call the series connection of cells and the effect of countering one electromotive force with another of equal magnitude.

In other experiments, Volta found that heating the water solutions rendered them more conductive and that nearly all salts improved the conductivity of water. He found that animal substances and their "humeurs" were, in general, better conductors than water. He theorized that when the "electric fluid" traverses conductors which are not perfect, it seeks to spread out in a large canal or to divide in many and to take detours, finding less resistance than to follow a single canal although that may be shorter.

Volta found a parallelism between the thin discs of his pile and the thin discs which constitute the electric organism of the torpedo, an electric fish. The latter he called the "electric organ natural" while his apparatus he called the "electric organ artificial."

Modifications of the Pile

In the latter part of his letter he reverted to the pile and described modifications in its construction to improve its life and portability. To make the pile more lasting as well as more portable, he suggested enclosing it in wax or pitch. This he said was a little difficult to do, yet he had made two piles which had served him for several weeks and he hoped that they might remain active for several months. With this construction he could use the pile in any position, vertical or horizontal. When the number of couples involved amounted to 60 or more, he advocated dividing the pile into two or more columns.

Volta found that the current of "electric fluid" excited not only the muscles of the body more or less violently, but also the organs of taste, of sight, of hearing, and of touch. One wonders that he did not do himself bodily harm in some of these experiments. Only the sense of smell was unaffected by the current. He thought of the "electric fluid" as flowing perpetually when the circle, as he called it, was closed.

Thus Volta gave to the world the first practical battery and with it a demonstration of convincing experiments. Many of his concepts are true today. He certainly had an implicit idea of electromotive force and the increase of it that came with additional cells. He was not able to express it except as the

shocks which he experienced became greater as he increased the number of couples in his pile or crown of cups. It is, therefore, entirely fitting that his name, shortened to the word volt, should have been chosen for the unit of electromotive force as we have it today.

Names for the electrical units were proposed in 1861, thirty-four years after Volta's death. At that time the Daniell cell was in common use and its electromotive force was proposed as a standard of electrical pressure, but under the leadership of Lord Kelvin the Electrical Standards Committee of the British Association adopted the absolute system of units proposed by Weber ten years previously. In this system the volt was defined as 10^8 centimeter-gram-second units. This and the other fundamental electrical units, which we have called the absolute units, were derived from the mechanical units of length, mass, and time by the use of accepted principles of electromagnetism, assuming the permeability of space to be unity in the cgs system. For both theory and practice this was a most important step, since electrical measurements were thereby made concordant with measurements in other fields of science and engineering.

Although this principle is to be greatly desired, the practical difficulties in making precise electrical measurements in terms of mechanical units are many. It is only within the past few years that such measurements have been accepted as sufficiently accurate to enable us to establish the absolute electrical units as a workable system for electrical engineering. It is only within the past two years that international agreement on this subject became effective. No detailed account of the efforts to reach this goal can be given here, except in very sketchy form.

The International Electrical Congress which met in Chicago in 1893 recognized in principle the absolute system of electrical units, but found it necessary to provide concrete standards to represent them. For the volt, the standard chosen at that time was the mercurous sulfate-zinc cell of Latimer Clark. The 53rd Congress of the United States passed a law, approved in 1894, embodying the decisions of this international body, but the law contained ambiguities which were not recognized until many years later.

Another International Conference on Electrical Units and Standards, meeting in London in 1908, took definitive action to recognize the absolute system of electrical units, yet here again it was found necessary to establish for practical purposes a separate and independent system based on the concrete standards of the mercury ohm, the silver voltameter, and the standard cell. The last named in this case was the Weston Normal cell which had demonstrated its superiority over the earlier cell of Latimer Clark. Thus the so-called international electrical units came into effect on January 1, 1911. The electromotive force of the Weston cell had been determined during the previous year by current and resistance measurements made at the National Bureau of Standards by an International Technical Committee, consisting of representatives of England, Germany, France, and the United States. It is a cherished memory of mine that I had a part, however small, in assisting this committee in establishing the basis for the volt. These international units were in use throughout the world from 1911 to 1947.

Revised values of the units of electricity and light, conforming to the best available data on the absolute values of them, became effective on January 1, 1948. These were adopted pursuant to decisions of the International Committee of Weights and Measures. The definitions of the new units and the methods of fixing their values are different from those formerly employed for the international units; however, the actual changes in magnitude are small and affect only the most precise measurements. I doubt whether many of you have noticed the difference resulting from this transition. As in the past, the units in this country for the ohm and the volt will be carried forward by means of resistors and standard cells kept at the National Bureau of Standards. The standard cells have a particular interest for me because it was my responsibility until the time of my retirement to keep and improve this standard of electromotive force. The standard cell appears on the badge of our Society.

My interest in Volta and his work is twofold. He gave us the first practical battery. The battery industry has grown from small beginnings. It is important in time of peace and war. Types and sizes of batteries and the applications for them have multiplied. In the second place, I am interested in Volta because of the volt, named in his honor. It, too, has been an important part of my life's work. I respect Volta for the work that he did.

In closing I pay homage to The Electrochemical Society. Membership in it for nearly thirty years has been of great benefit to me, as I know it has been to you. It stands for a most interesting and important branch of Science and Technology. It is the natural and recognized forum for presentation of electrochemical research in diverse branches. I am happy that today the Society has a Battery Division included in its organization.

The honor that the Society has given me in the award of the Acheson Medal is beyond any expectations that I may have had. It is a high honor that I prize most dearly. To the Society and to the individual members of it I tender my most sincere thanks. May the Society continue to prosper and grow in importance among the great scientific organizations of our time.

IMPORTANT NOTICE TO AUTHORS

Triplicate copies of manuscripts or abstracts to be considered for the Spring Meeting must be in the Secretary's office, 235 West 102nd Street, New York 25, N. Y., not later than *February 1, 1951.*

The dates of the Spring Meeting, which will be held in Washington, D. C., are April 8–12. Scheduled symposia will be: Electrode Kinetics, Electric Insulation, Gaseous Electronics, Luminescence, Rare Metals, and Attainment and Measurement of High Temperatures.

Current Affairs

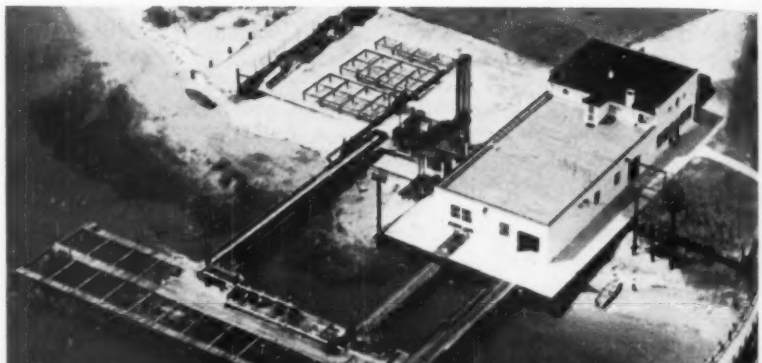
Marine Corrosion Laboratory Dedicated

The world's finest laboratory and test station for the study of marine corrosion was opened and formally dedicated at Harbor Island, near Wilmington, North Carolina, on November 15th. This station, established by the International Nickel Company, is the outgrowth of fifteen years' experience in testing the action of salt water and marine organisms on metals, finishes, wood, plastics, and other materials. The new laboratory is located a few miles north of the original station at Kure Beach, so well known to those interested in marine corrosion. The atmospheric test racks at Kure Beach with their 20,000 specimens will be maintained at the original location.

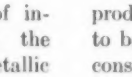
The new Harbor Island Station consists of a well-equipped laboratory where quantitative data are being obtained on the influence of the many variables involved in sea water corrosion and marine fouling. Outside the laboratory are extensive installations for the study of pipe design and the effect of chlorination treatments. Facilities are provided for full-scale tests of marine piling and for the immersion of thousands of specimens of metals and other materials in sea water.

The dedication ceremonies were attended by several high officials of the Navy and by representatives of about 100 companies who have in recent years participated in or been invited to follow the progress of the work at Kure Beach. These men are all members of the Sea Horse Institute, an informal organization founded by Mr. F. L. LaQue who is in charge of the Kure Beach and Harbor Island projects. Members of this Institute are privileged to wear the tiny sea horse insignia.

The International Nickel Company is to be commended for the establishment of these facilities which are of such importance in getting at the facts of marine corrosion. The information obtained is becoming of increasing importance to both the manufacturers and users of metallic products and in a larger sense is coming to be a significant contribution in the conservation of natural resources.



AIR VIEW OF NEW HARBOR ISLAND LABORATORY AND CORROSION TESTING STATION



Washington Plans Ninety-ninth Meeting

Members who would enjoy a visit to Washington in the spring should make arrangements now to attend the Society's next semi-annual meeting, to be held in the capital city, Sunday through Thursday, April 8th to 12th. Board and committee meetings will be scheduled for Sunday; technical sessions will run Monday through Thursday.

Convention headquarters will be at the Wardman Park Hotel, Connecticut Avenue at Woodley Road, N. W. Requests for room reservations should be made preferably on the special reservation cards sent to the members. Otherwise, such requests may be made directly to the Wardman Park Hotel with mention of The Electrochemical Society.

Present plans indicate that at least 16 technical sessions will be scheduled. Symposia are being arranged on the following subjects: Electrode Kinetics, Electric Insulation, Gaseous Electronics, Luminescence, Rare Metals, and Attainment and Measurement of High Temperatures. In addition, a round-table discussion will be sponsored by the Industrial Electrolytic Division.

The selection of Washington for the spring convention was partly motivated by the celebration of the semi-centennial of the founding of the National Bureau of Standards, which

will occur at the same time. The Bureau will be open to members and guests of The Electrochemical Society during this celebration. Excellent transportation is available between the Wardman Park Hotel and the Bureau of Standards.

Washington is not a manufacturing city. In lieu of factories, visitors will find outstanding laboratory facilities and personnel at the Bureau of Standards on Connecticut Avenue; the College Park Station of the Bureau of Mines, College Park, Maryland; the Naval Ordnance Laboratory, Whiteoaks, Maryland; the Naval Research Laboratory, Anacostia, D. C.; and the Department of Terrestial Magnetism, Carnegie Institute, Washington. Those interested in the biological sciences may visit the Beltsville Station of the Department of Agriculture, the Institute of Public Health, and the U. S. Naval Medical Center. Local universities of interest include Maryland, George Washington, Catholic University, Howard, and Georgetown.

As a city, Washington will offer many attractions to members and guests of the Society. The Capitol, the White House, Rock Creek Park, the Tidal Basin with its cherry trees in bloom, Mt. Vernon, and the beautiful drives along the Potomac River are only a few of its major points of interest. Visitors will have no worries about what to do when not attending technical sessions.

Gaseous Electronics Symposium

A Symposium on Gaseous Electronics will be held during the forthcoming Washington Meeting of the Society, April 8–12, according to a recent announcement by the General Electronics Group, D. H. Wamsley, Chairman. All interested persons are invited to attend.

If you or your associates plan to present a paper at this session, please let us know as early as possible. Abstracts, and preferably completed manuscripts, should reach the Secretary of the Society no later than February 1st. Please send titles and papers to:

Dr. Henry B. Linford, Secretary
The Electrochemical Society, Inc.
235 West 102nd Street
New York 25, N. Y.

An informal discussion will follow the presentation of papers.

In addition to the session on Gaseous Electronics, the Electronics Division is also arranging symposia on Rare Metals and Luminescence. These will be scheduled so as not to coincide with the Gaseous Electronics discussion. Every effort will be made to have satisfactory meeting and discussion facilities available.

Large Chlorine Plant to Use De Nora Cell

The first large chlorine plant in the United States or Canada to use De Nora mercury-type cells with a rated capacity of 30,000 amperes will be erected by Marathon Paper Mills of Canada, Ltd., at Marathon, Ontario, as the result of a contract signed recently by Marathon, Monsanto Chemical Company, and the Leonard Construction Company of Chicago.

Designed by Monsanto, the plant will be built to produce 25 tons of chlorine a day, and will manufacture rayon-grade caustic soda, electrolytic sodium sulfide, sodium hypochlorite, and synthetic hydrochloric acid.

DIVISION NEWS

Electrothermic Division

The following candidates have been nominated and the nominations accepted for election at the meeting of the Electrothermic Division, to be held during the 1951 Spring Meeting of The Electrochemical Society:

Chairman—C. H. Chappell
Vice-Chairman—A. E. Pavlish
Secretary-Treasurer—I. E. Campbell
Members-at-Large—Guy Fetterley and A. P. Thompson

Submitted by the Nominating Committee: A. T. Hinckley, Chairman; R. G. Brown and R. B. Hammond, members.

SECTION NEWS

Chicago Section

Dr. Clark E. Thorp, head of the Research Department of the Armour Research Foundation, Illinois Institute of Technology, gave a very interesting talk on "The Technology of Ozone" before the Chicago Section at its November 3rd meeting at the Chicago Engineers' Club.

Dr. Thorp, who is engaged in the Institute's research on the industrial applications of ozone, discussed how it may best be handled and reviewed some of the new uses for this interesting polymer of oxygen.

Ozone, he said, is a powerful oxidizing agent that will literally burn up impurities in water and in air. It will bleach, deodorize, or purify effectively, but its high oxidizing power makes it difficult to manipulate.

Dr. Thorp has taken a leading part in the research on ozone and has helped to make it available for commercial uses. In a current technical article, he has charted the little-known ozone toxicity tolerances.

J. H. Conolly, *Secretary*

Cleveland Section

For its November meeting, the Cleveland Section of The Electrochemical Society sponsored, jointly, the Second Annual Dinner of the Chemical Profession in Cleveland, with the American Institute of Chemists, American Institute of Chemical Engineers, and the American Chemical Society. The meeting took place at the Hotel Hollenden on November 9th. Attendance was approximately 275.

Howard E. Fritz, vice-president of the B. F. Goodrich Rubber Company, acted as toastmaster, and entertainment was provided by Dr. H. C. Froelich who played several classical piano selections. Opinion was that Dr. Froelich could easily qualify as a concert pianist if ever he should tire of being an electrochemist.

The speaker of the evening, Dr. Sidney D. Kirkpatrick of the McGraw-Hill Publishing Company, New York, chose as his subject "The Chemical Profession and National Security."

A new set of ABC's—atoms, bugs, and chemicals—will be taught to us by any war of the future, Dr. Kirkpatrick said. "The atomic bomb project is primarily a chemical achievement; it was the chemical engineer who took the laboratory research of the nuclear physicists and chemists and translated it into the great plants in this country," he asserted. "And many of the great chemical companies aided the government in managing the $2,000,000,000 project."

As for bugs in warfare, the speaker said it is unpleasant to think about waging war by spreading disease, yet the practice is as old as civilization itself. We must be prepared for bacterial warfare, he said, in the event that it is used against our troops. From the military research in this field he believed new industries may result

which will minister to the health, comfort, and safety of mankind.

Chemicals, the C of the possible ABC warfare of the future, are not the horribly inhumane things that they have come to be held, he maintained, but we must be ready to defend ourselves against the new nerve gases and other deadly agents.

Dr. Kirkpatrick closed by stressing the seriousness of neglecting or wasting our most valuable resources of science and technology.

L. E. PUCHER, *Secretary*

Midland Section

At a recent meeting of the Executive Committee of the Midland Section of The Electrochemical Society, committees for the 1950–51 season were appointed as follows:

Program Committee—H. A. Robinson, R. E. Friedrich, P. P. George

Membership Committee—H. H. Roth, H. A. Humble, R. D. Blue, F. N. Alquist

Nominating Committee—P. R. Jucknies, R. C. Kirk, L. A. Matheson

Auditorium Arrangements—Don Chapin

Executive Committee—F. W. Koerker, H. A. Robinson, H. H. Roth

H. H. ROTH, *Secretary*

New York Metropolitan Section

The Metropolitan Section's second meeting of the season, held on November 8th at the Holley Hotel, was well attended and an interested audience heard a most complete survey of new developments in the plating field by Mr. Nathaniel Hall, a consultant in metal finishing and member of the firm of G. B. Hogaboom, Jr. & Company.

Mr. Hall confined his remarks to developments of commercial importance and principally those which have been introduced commercially since World War II, even though they might have been developed in the laboratory stage previous to that time.

In the field of preparation the speaker's principal emphasis was given to mechanical buffing, liquid abrasives, and chemical polishing. Other matters covered were diphase cleaners, sodium hydride descaling, and plating on aluminum and magnesium.

Turning to actual plating practice, Mr. Hall reviewed the situation with regard to the competition between motor generators and rectifiers: the reasons for the trend back to motor generators, and the recent introduction of oil-cooled rectifiers which may reverse this trend. He believes that the principal advance in plating practice since the war was the development of PR plating which had markedly cut polishing costs in the plating shop.

Mr. Hall pointed out that three new solutions of importance have been introduced: a tin-zinc alloy solution which gives promise of helping to relieve the cadmium shortage; speculum plating which although it has had very little acceptance in America is extensively used in England, and might become interesting as a substitute for nickel in decorative applications; and third, advances in chromium plating solutions including barrel plating and the recently introduced high speed solution.

The subject of leveling was discussed briefly, and mention was made of many other recent developments including multicolor dyeing of anodized aluminum, waste disposal, recovery of metals and chromic acid by ion exchange, hot lacquers, electrostatic spraying and detearing, and plastisol rack coatings.

F. A. LOWENHEIM, *Secretary-Treasurer*

Niagara Falls Section

A joint meeting of the Niagara Falls Section of The Electrochemical Society with the Western New York Section of the American Electroplaters' Society was held on Wednesday, November 8, 1950, at the Red Coach Inn, Niagara Falls, New York. Mr. John Davis, chief engineer, and Dr. R. B. Saltonstall, technical director, of the Udylite Corporation, Detroit, showed a sound film entitled "A Better Way in Plating" and spoke on the following subjects:

Mr. Davis, "Advantages in the Use of Automatic Equipment in Plating"

Dr. Saltonstall, "Recent Trends in Developments in Electroplating"

In their talks, the speakers discussed and compared the three types of automatic plating machines, viz., straight line, return, and rotary.

Summarizing, the savings in full automatic operation as compared to hand operation were given briefly:

1. Less floor space required.
2. Deeper tanks can be used.
3. Larger and heavier racks can be used.
4. Drag-out may be reduced because of proper lift rate control.
5. Contamination of baths is reduced because of reduced drag-out.
6. Fewer racks required.
7. Ventilation can be more effectiv because more of the top of the tank may be covered.
8. Installation cost may be reduced by shipping preassembled units.
9. Production rate is not affected to such a degree by human factors.
10. Process control. Definite reproducible time schedules are more subject to control.
11. Uniformity of results are improved because of the factors discussed under 9 and 10.
12. Rejects may be reduced.
13. Miscellaneous supplies such a gloves, rubber gloves, boots, etc. are reduced.

M. S. KIRCHER, *Secretary-Treasurer*

Philadelphia Section

The first meeting of the 1950-5 year of the Philadelphia Section was held on November 1st at the Harrison Laboratory, University of Pennsylvania, Philadelphia. A dinner at the Lenape Club in honor of the speaker, J. Fred Hazel of the University of Pennsylvania, and Secretary of the Philadelphia Section, preceded the meeting. Fifty-one members and guests attended the dinner and about 75 attended the technical meeting.

Dr. Hazel addressed the Section on "Streaming Potential Measurements and Adhesion of Phosphors on Cathode Ray Screens." He is currently engaged in the study of solid surfaces (phosphor and glass) and solutions used in the preparation of television screens. In this work the potential difference originating from the flow of the solutions over the surfaces is measured.

Dr. Hazel explained that the coating of glass with phosphor to produce fluorescent surfaces on cathode-ray tubes requires a medium which will promote adhesion of phosphor to glass. A mixture of potassium silicate with an addition agent, such as barium acetate or sodium sulfate, is employed as the adhesive. While the mixture gives satisfactory results, the separate components are relatively ineffective, and in the case of potassium silicate may actually cause the phosphor to be repelled by the glass. The speaker also discussed the relationship between adhesion and the electrical properties of the surfaces. He illustrated the lecture with experiments and slides.

San Francisco Section

San Francisco opened its current season with a dinner at the St. Julien Restaurant on October 18th followed

by a technical discussion on "Electrolytic Zinc" by Mr. Emo D. Porro of Stanford Research Institute.

Mr. Porro reviewed the present status of zinc and discussed the methods by which it is produced. Zinc is among the most important of the nonferrous metals, ranking second to copper in the United States; its use surpassed that of lead in the past decade. Zinc is produced in this country by one of two processes: The oldest process is that of smelting zinc ore and producing zinc vapor which is later condensed and recovered; the other process is electrolytic and in this the ore is roasted, the zinc leached out, the leaching solution purified and then electrolyzed.

The original large-scale smelting process was inefficient and required a large amount of labor but new developments involving continuous operation have proved quite successful. One of these methods uses an electric furnace.

The speaker next reviewed the electrolytic processes of which there are two, an acid and an alkaline process. The acid process is used extensively in commercial installations and is very satisfactory for all zinc ores and concentrates except those high in carbonate and silica. The alkaline process, on which Mr. Porro has been doing some of the experimental work at Stanford, is still in the development stage. It is particularly adaptable to high carbonate-silica ores. The production costs of the two processes are comparable but some of the technical aspects of the alkaline process are troublesome, the principal drawback being the poor location of suitable ore deposits rather than the process itself.

Mr. Porro's talk was well received and prompted a lengthy discussion period.

R. F. Bechtold, *Secretary-Treasurer*

Washington-Baltimore Section

An interesting and timely symposium on "The Present Status of Titanium as an Engineering Material" constituted the first technical meeting of this year for the Washington-Baltimore Section. The program was arranged by Dr. R. S. Dean, Consulting Engineer, Washington, D. C. During his former employment with the U. S. Bureau of Mines, Dr. Dean played an important part in initiating the Bureau of Mines' work on the development of methods of preparation of pure titanium. Approximately 200 people attended this meeting which was held November 16th at the National Bureau of Standards.

Edward A. Gee of E. I. du Pont de Nemours and Company, Newport, Delaware, reviewed the methods of preparing pure titanium and indicated that sizable quantities were available for experimental purposes and that greater production would be available if and when there was sufficient demand. George F. Bond of P. R. Mallory and Company, Indianapolis, Indiana, reviewed the methods for preparing alloys of titanium which are now available and described some of the possible applications of these alloys. James R. Long of the Bureau of Mines, College Park, Maryland, described the powder metallurgy method of preparing pure titanium and reviewed the methods of welding titanium. The powder metallurgy method has been used primarily because of its simplicity and not necessarily because it is better than the other methods. Nathan R. Promisel of the Bureau of Aeronautics, Navy Department, Washington, D. C., outlined the vast number of uses of titanium and its alloys, particularly in the aeronautical field. W. Lee Williams of the U. S. Naval Engineering Experiment Station, Annapolis, Maryland, described the corrosion properties of titanium and some of its alloys—particularly in marine atmosphere and sea water.

An interesting discussion period followed the above talks. This full evening certainly brought out the fact that this newcomer to the field of metallurgy has vast potentialities but there remains much to be done in order to evaluate its possibilities.

J. C. White, *Secretary-Treasurer*

India Section

The second technical meeting of the India Section of The Electrochemical Society was held on November 2, 1950, at the Indian Institute of Science, Bangalore, with Dr. B. K. R. Prasad in the chair.

Mr. J. Balachandra, Lecturer in Electrometallurgy, Indian Institute of Science, and Society member, presented a paper on "Electroplating of Metals from Fluoborate Baths." Mr. Balachandra stated that fluoborate baths had been found to present a combination of features hitherto not realized in most of the present day plating baths. These baths, he said, had all the desirable qualities of the acid type bath, viz., high conductivity, good cathodic and anodic current efficiencies, nonpoisonous nature on the one hand, and good throwing power of the cyanide bath on the other. They were superior to the other types of baths in respect to high metal content that can be employed, ready solubility in water, satisfactory deposition even at high current densities, ease of maintenance, and stability.

Copper, zinc, tin, and nickel fluoborate baths were compared with other plating baths, with special reference to preparation, maintenance, and operating characteristics. Work done by the speaker and his co-workers on cadmium, zinc, and nickel fluoborate baths was referred to, pointing out the special advantages of these baths over other types.

After an interesting discussion in which many members participated, the meeting was adjourned.

* * *

The India Section, with the approval of the Board of Directors, has begun to invite electrochemical and allied industries in India to contribute toward the support and development of the Section by becoming "Patrons of the India Section of The Electrochemical Society." The Section is pleased to announce the following companies as the first Patrons:

1. The Travancore and Mettur Chemicals, Alwaye
2. The Mysore Paper Mills Ltd., Bhadravati
3. Indian Aluminum Company Ltd., Alwaye
4. The Aluminum Corporation of India Ltd., Calcutta

T. L. Rama Char, *Secretary-Treasurer*

PERSONALS

Joseph J. Cordiano is now affiliated with the U. S. Metals Refining Company of Carteret, New Jersey. Mr. Cordiano was previously located in Painesville, Ohio.

Francis E. Pohl has joined the staff of Singmaster and Breyer, chemical engineers and metallurgists, New York City, and is located as resident engineer in Oak Ridge, Tennessee.

Harry M. Fisher has accepted a position as technical supervisor at the Natrona Plant of the Pennsylvania Salt Manufacturing Company at Natrona, Pennsylvania. Mr. Fisher had been with the Foote Mineral Company of Philadelphia.

S. J. SINDEBAND has been appointed Executive Vice-President of Mercast Corporation, 295 Madison Avenue, New York City. Mr. Sindeband was formerly connected with the American Electro Metals Corporation, Yonkers, New York.

MARTIN F. QUAELY is now connected with Westinghouse Electric Corporation, in the capacity of research engineer, in the Research Department, Lamp Division, Bloomfield, New Jersey.

K. SESHADRI is now associated with the National Chemical Laboratory of India, at Poona, as research chemist in the Division of Inorganic Chemistry. Mr. Seshadri was formerly with the Council of Scientific & Industrial Research at Bangalore.

K. L. RAMASWAMY, Deputy Production Superintendent of the Government of India Fertilizer Project, Sindri, has been made Assistant Technical Advisor in the Project.

JOSIAH WORK, consultant, of Los Angeles, has been named Staff Consultant of Food Machinery & Chemical Corporation, Westvaco Chemical Division, Pocatello, Idaho.

JOHN T. MILEK has joined the Hughes Aircraft Company, Culver City, California, as supervisor of the Research and Development Laboratories' library. The company is engaged in Electronics and Guided Missile research and development. Mr. Milek was formerly with Babcock & Wilcox Company, Alliance, Ohio.

FRANK HOVORKA, director of the chemistry laboratories, Western Reserve University, Cleveland, Ohio, has been appointed chairman of the division of chemistry, succeeding the late Dr. H. S. Booth.

CLIFFORD HAMPEL, Armour Research Foundation, Chicago, recently visited chemical plants in Italy and addressed a conference at the Politecnico in Milan on chlorine industries in the U. S.

W. BECK, formerly Associate Professor of Metallurgy and Director of Corrosion Research at Lehigh University, Bethlehem, Pennsylvania, is now Consulting Chemist and Chemical Engineer with offices at 780 Riverside Drive in New York City.

NEW MEMBERS

In November 1950 the following were elected to membership in The Electrochemical Society:

Active Members

GEORGE E. BEST, Mutual Chemical Company of America, 1348 Block Street, Baltimore 31, Maryland (Corrosion)

AGNES E. CRAIG, National Union Radio Corp., mailing add: 156 South Munn Avenue, East Orange, New Jersey (Electronics)

EDWARD GREGORY, Westinghouse Electric Corporation, mailing add: 16 East Passiac Street, Rochelle Park, New Jersey (Electrothermic)

MOSES D. HEYMAN, Integrated Mica Corp., 202 Franklin Place, Woodmere, New York (Battery, Electric Insulation and Theoretical Electrochemistry)

HARRY HUTZ, Reading Batteries Inc., P.O. Box 916, Reading, Pennsylvania (Battery)

WARREN D. SHERROW, Great Lakes Carbon Corp., Electrode Division, Niagara Falls, New York (Industrial Electrolytic)

Reinstatements

CHARLES F. BONILLA, Department of Chemical Engineering, Columbia University, New York 27, New York (Electrodeposition and Electrothermic)

NAOTO KAMEYAMA, University of Tokyo, mailing add: No. 10, Nishikata-machi, Bunkyo-ku, Tokyo, Japan (Theoretical Electrochemistry, Battery, Corrosion, Electrodeposition and Electrothermic)

Associate Members

THEODORE R. BEATTY, National Carbon Division, Union Carbide and Carbon Corporation, mailing add: 15005 Braemar Drive, Cleveland 11, Ohio (Battery)

WILLIAM W. GULLETT, Chicago Development Company, Inc. mailing add: 6903 Baltimore Avenue, College Park, Maryland (Battery)

DAVID A. ROBINSON, Cerro de Pasco Copper Corporation, La Oroya, Peru (Electrodeposition)

Student Associate Member

ANAND MOHAN, Department of Metallurgy, Indian Institute of Science, Bangalore 3, India (Electrodeposition)

BOOK REVIEWS

CHEMICAL THERMODYNAMICS by Frederick D. Rossini. Published by John Wiley & Sons, Inc., New York, 1950. 514 plus XIX pages, $6.00.

Dr. Rossini has long been an outstanding worker in the applications of chemical thermodynamics, and his book reflects this experience in its emphasis on the practical aspect of the subject. He proceeds logically and clearly from the fundamentals to the application of thermodynamic data to the solution of chemical problems and methods of calculation.

After five introductory chapters dealing with definitions of terms and units, the concepts of energy and entropy are introduced and related to the physical state of substances. This is done simply and concisely and without most of the historical background usually found in textbooks of this sort. The more involved mathematical treatments are avoided; nevertheless, the presentation is rigorous and in sufficient detail to enable the student to obtain a quantitative grasp of the subject. For completeness, a short chapter on the equivalence of mass and energy, and a brief survey of the application of statistical methods are included, even though these subjects are beyond the realm of classical thermodynamics.

Following a development of equilibrium theory the concepts of fugacity and activity are presented with a discussion of the properties of real and ideal solutions. The theory of electrolytic solutions is presented briefly and the application of the Debye-Hückel theory to the thermodynamic properties is included. A chapter is devoted to applications of thermodynamics to systems under external fields, with a section on surface tension and elasticity. An excellent chapter on thermodynamic calculations, including the evaluations of equilibrium conditions, heats of vaporization, and fractionating processes, together with several examples, concludes the text. An extensive compilation of the sources of thermodynamic data is included which should be found invaluable to the student.

An excellent bibliography is included at the end of each chapter which provides historical material as well as more advanced treatments of special topics.

D EDELSON

LARGE MODERN ELECTROLYTIC FURNACES FOR THE MANUFACTURE OF ALUMINIUM by Louis Ferrand. Available at office of *Journal du four électrique*, 86 Rue Cardinet, Paris. 500 frs. for French version and 750 for English translation, in France; 600 frs. elsewhere. Published 1950, 55 pages, paper bound.

This pamphlet describes the various forms of modern cells used in the production of aluminum primarily from the point of view of economy, both of electrical energy and material handling.

The various losses of energy are listed, and the possible reduction in these wastes is discussed. The principal savings are shown to result from proper cell construction to conserve heat loss, and automatic control to maintain optimum current density and solution composition. Improvements in cell design to cut down losses due to hand labor are discussed. The details of the automatic regulation are clearly described. A bibliography listing journal and patent references is included. Most of the references are, however, of foreign origin.

HENRY B. LINFORD

RECENT PATENTS

Selected for electrochemists by Fred. W. Dodson, Chairman of the Patent Committee, from the Official Gazette.

September 26, 1950

Du Rose, A. H., and Moy P. W., 2,524,-010, Electrodeposition of Nickel

October 3, 1950

Chester, A. E., and Reisinger, F. F., 2,524,040, Electroplating of Zinc and Electrolyte Therefor

Klein, S., 2,524,227, Thermionic Emitting Device

Pelfrey, L. S., 2,524,270, Selenium Rectifier

Butler, E. M., 2,524,511, Self-Energizing Electrolytic Water Correction Assembly

Brown,H., 2,524,619, Electrodeposition of Nickel

Brown, H., 2,524,648, Electrodeposition of Nickel

Keller, F. A., 2,524,668, Dry Cell

Payne, E. C., Hayes, M. L., and Demb K., 2,524,733, Fluorescent Coating Material Containing Ethyl Cellulose

October 10, 1950

Thomson, E. C., Re. 23,282, Electrode System

Jernstedt, G. W., 2,524,912, Process of Electrodepositing Copper, Silver, or Brass

Gonze, M., 2,524,970, Photochemical Preparation of Benzene Hexachlorides

Froelich, H. C., 2,525,028, Preparation of Silicate Phosphors, Including Firing in the Presence of Steam

Whiting, L. R., and Waugner, P. F., Jr., 2,525,107, Coating Composition for Metals

Macksoud, M. E., 2,525,262, Method of Producing Highly Emissive Electrodes

Macksoud, M. E., 2,525,263, Method of Producing Highly Emissive Electrodes

Quinnell, La V. E., 2,525,270, Electric Primary Cell

Williams, F. D., Jr., 2,525,436, Dry Cell

Abbott, R. W., 2,525,439, Thermocouple

Sorg, H. E., Williams, P. D., and Drieschman, D. F., 2,525,565, Filamentary Cathode for Electron Tubes

Tucker, W. M., and Flint, R. L., 2,525,-567, Silver Strike Electrolyte and Process of Plating

Glesner, J. G., and Robinson, M. O., 2,525,665, Packaged Galvanic Anodes for Cathodic Protection

October 17, 1950

Albrecht, K., 2,525,754, Conductivity Cell

Byler, W. H., and Wilson, J. W., 2,525,860, Phosphors and X-Ray Screens Prepared Therefrom

Ferguson, V. H., 2,525,882, Electric Ladle Furnace

Ferguson, V. H., 2,525,883, Electric Ladle Furnace

Peck, L. H., 2,525,938, Electrochemical Apparatus with Adjustable Electrode

Proell, W. A., 2,525,942, Electrodepositing Bath and Process

Proell, W. A., 2,525,943, Copper Plating Bath and Process

Nelson, H., 2,526,038, Leak Detector for Evacuated Systems

West, J. Jr., and Pridham, E. S., 2,526,101, Primary Dry Cell

Biggle, L. C., 2,526,112, Thermopile Structure

La Burthe, P. H., and Lambert, R. E., 2,526,241, Electrode Seal for Glass Furnaces

Medlar, L. A., 2,526,251, Thermally Responsive Impedance Unit

Liston, M. D., and Opperman, K. W., 2,526,491, Thermopile

Liston, M. D., and Opperman, K. W., 2,526,492, Thermopile

Szper, J. A., 2,526,591, Filling Material for Secondary Dry-Accumulator Batteries

October 24, 1950

Daniel, A. F., 2,526,640, Primary Cell

Ruben, S., 2,526,692, Primary Cell and Battery

Woodring, W. B., 2,526,789, Dry Cell

Chaney, P. E., 2,526,857, Method for Logging Wells

Jouannet, R., 2,526,875, Method of Collecting Gases in Aluminum Furnaces

Sejersted, J., 2,526,876, Method of Handling Continuous Electrodes

Kay, O., 2,526,878, Process for Shipping Caustic Soda Liquors

Kiefer, J. M. Jr., 2,526,951, Method of Electrolytic Polishing

Diggin, M. B., and Kardos, O., 2,526,-999, Cadmium Plating Bath

Bischoff, A. F., 2,527,209, Storage Battery

Garner, S. R., 2,527,212, Battery Terminal Clamp

Bailey, B. L., 2,527,294, Carbon Electrode

Hunter, R. M., 2,527,361, Packaged Magnesium Anode with Compacted Backfill

Leverenz, H. W., 2,527,365, Doubly Activated Infrared Phosphors

October 31, 1950

Arditi, M., and De Santis, V. J., 2,527,513, Nonemissive Electrode for Use in Electron Discharge Devices

Arditi, M., and De Santis, V. J., 2,527,514, Nonemissive Electrode for Use in Electron Discharge Devices

Ruben, S., 2,527,576, Flat Primary Cell

Turner, D. W., 2,527,690, Electrical Apparatus for Treating Emulsions

Lewis, M. N., and Miller, P. H. Jr., 2,527,747, Apparatus for Coating Articles by Thermal Evaporation

Milnes, H. R., 2,527,888, Alkaline Storage Battery

Cartoux, H. G. M., 2,527,914, Electric Tilting Furnace

Kline, B. L., 2,528,005, Electrosensitive Recording Blank

Richardson, R. P., and Lewis, R. W., 2,528,178, Primary Electric Cell

Daily, R. A., Hindall, A. L., Mahoney, D. G., Miller, B. A., and Bish, R. H., 2,528,266, Battery Charging and Forming Apparatus

Roberts, J. B., Gage, H. B., and Brautcheck, C. H., 2,528,320, Continuous Photochemical Preparation of Aliphatic Sulfonyl Chlorides

Mitchell, A. G., 2,528,384, Deposition of Materials by Sedimentation

November 7, 1950

Lowenheim, F. A., 2,528,601, Copper-Tin Alloy Plating

Batcheller, C., 2,528,717, Method of Electroplating Stainless Steels and Irons

Kohl, A. L., 2,528,889, Solution Concentration Indicator

Lawson, H. E., 2,528,891, Primary Battery Depolarizer and Method of Making the Same

Moy, P. W., and Karash, W. P., 2,528,902, Bright Nickel Plating

Ollivier, P. J. M. C., and Perieres, R. A. P. G., 2,528,905, Construction of the Lower Portion of Igneous Electrolytic Cells

Oppenheimer, F., 2,528,969, Lamp

Medlar, L. A., and Godshalk, J. B., 2,529,038, Maximum Temperature Cutoff System for Battery Chargers

Müller, P., 2,529,041, Method of Artifically Producing Carbonaceous Composition Pieces

Law, H. B., 2,529,086, Method of Making Fine Mesh Screens

Arnold, F. R., 2,529,123, Storage Battery Charging System

Chadwick, L. S., 2,529,137, Apparatus for Producing Vaporous Ozonides

Evans, E. A., and Porter, G. H., 2,529,144, Resistance Material

Turner, J. L., and Alessandroni, H. V., 2,529,237, Electro-Recovery of Metals

Thys, E., 2,529,319, Arc Furnace Tilting and Adjusting Mechanism

FUTURE MEETINGS OF OTHER ORGANIZATIONS

Society of Plastic Engineers, 7th annual national technical conference, Hotel Statler, New York City, January 18–20.

American Society of Heating and Ventilating Engineers, 57th anual meeting, Philadelphia, Pennsylvania, January 22–25.

American Institute of Electrical Engineers, 1951 winter meeting, Hotel Statler, New York City, January 22–26.

American Society for Testing Materials, spring meeting and committee week, Cincinnati, Ohio, March 5–9.

NOTES FROM INDUSTRY

Products

Penfield Manufacturing Company of Meriden, Connecticut, has announced a new ion exchange demineralizer for laboratories and other users of up to 10 gallons per hour of high purity, demineralized water. The new unit has a permanent cartridge and is equipped with an exclusive flow meter, providing efficient performance at low operating cost. Details sent upon request.

Eastman Kodak Company, Rochester, New York, has introduced a new Kodak Chemical Scales which are highly efficient and streamlined. The scales are marked for both avoirdupois and metric systems. Features include deep pans with handles and pouring lips, a sliding beam weight, and metal parts finished in noncorrosive chrome or polished aluminum. Available from all Kodak dealers.

Aluminum Company of America, Pittsburgh, Pennsylvania, has developed a new method for applying a seamless aluminum sheathing to telephone and electric power cables. The seamless aluminum sheathing is thinner, stronger, and lighter than the usual lead sheathing. Also it is softer and more flexible than aluminum sheathing produced heretofore. Substantial lengths are now being tested by a number of cable manufacturers.

Publications

Burrell Corporation, 2223 Fifth Avenue, Pittsburgh, Pennsylvania, has announced Catalog No. 450, a new all-inclusive reference work on laboratory apparatus and supplies. Contains 986 pages, listing 25,000 items. Free copies to firms, institutions, and laboratories.

RCA Tube Department, Radio Corporation of America, has issued a new revised edition of the booklet "RCA Receiving Tubes for AM, FM, and Television Broadcast" (Form No. 1275-E). Included are more than 450 RCA receiving tubes and kinescopes, of which 50 are new tube types. Available from RCA Tube distributors.

Hevi Duty Electric Company, Milwaukee, Wis., will send on request the new Hevi Duty bulletin HD-750 containing descriptions and illustrations of the tap changing transformers for furnace control and general variable voltage use. Available in a wide range of sizes.

General Electric Company's Meter and Instrument Divisions have announced a new Manual of Instrument Transformers, profusely illustrated, 76 pages. The Manual (GET-97A) covers the theory of operation and application and is written for practicing engineers and students. Priced at $1.00, available from Apparatus Dept., General Electric Co., Schenectady 5, New York.

American Chemical Paint Company, Ambler, Pennsylvania, has released the folder "ACP Phosphate Coating Chemicals and Processes," containing valuable information on paint bonding, rust proofing, protecting friction surfaces, and improving drawing and extrusion. Available on request.

Chemical Translations
by mail
Werner Jacobson, B.S., M.S.
Translator and Chemist
Microfilms Accepted
German, Swedish, Danish-Norwegian, French, Spanish, Portuguese, Italian, Russian, Polish, Chinese.
334 South Mozart Street Chicago 12

EMPLOYMENT SITUATIONS

Please address replies to box shown, c/o The Electrochemical Society, Inc., 235 West 102nd Street, New York 25, N. Y.

Positions Available

Research Chemist or Physicist, B.S. or M.S., young man, at least 2 years' experience, preferably in electrochemistry, inorganic chemistry, or physics of solids. Research and development work in battery field, North Jersey. State qualifications and expected salary. *Reply to Box A-219.*

Electrochemist, M.S. or Ph.D., with experience mainly in electroplating and electroforming techniques for advanced development in the electron tube industry in southeastern Pennsylvania. *Reply to Box A-220.*